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FINAL REPORT, VOLUME VI

MIE SCATTERING AND ABSORPTION CROSS SECTIONS OF

ALUMINUM OXIDE AND MAGNESIUM OXIDE

Gilbert N. Plass

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SPACE SYSTEMS DIVISION
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Los Angeles, California

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AERONUTRONIC DIVISION
FORD MOTOR COMPANY

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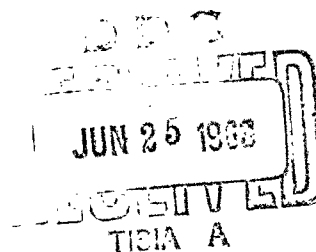ALUMINUM OXIDE AND MAGNESIUM OXIDE

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ABSTRACT

The scattering and absorption of electromagnetic radiation by spherical particles of aluminum oxide and magnesium oxide is calculated from the Mie theory. The complex index of refraction was taken from the best available experimental data. Tables of the efficiency factors for scattering, absorption, and extinction are given for particle radii from 0.1 to 5.1μ and a range of wavelengths from 0.5 to 10 μ.

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SECTION 1

INTRODUCTION

Particles of aluminum oxide and magnesium oxide occur in many different types of flames including those from solid propellant rockets. In order to understand the emissivity of these flames it is important to know the contribution of these particles.

The absorption and scattering cross sections of these particles were calculated from the Mie theory for a range of particle radii from 0.1 to 5.1μ and a range of wavelengths from 0.5 to 10μ. The complex index of refraction was chosen after a study of the best available measurements.

SECTION 2

MIE ABSORPTION AND SCATTERING CROSS SECTIONS

Measurements of the complex index of refraction of sapphire (aluminum oxide) have been made by a number of authors. The real part of the index has been measured only at room temperature. The values given in Table 1 were adopted after plotting the measurements of Malitson, Murphy, and Rodney[1] and Malitson[2] and using the dispersion equation given in the latter article. The imaginary part of the index has been measured at temperatures of 1000°C as well as at room temperature. The values given in Table 1 are obtained by combining absorption measurements of several authors[3,4] made at 1000°C.

The measurements of the complex index of refraction for magnesium oxide have recently been reviewed by Bauer.[5] The values given in his figures are based on measurements of Burstein, Oberly, and Plyler[6] and on unpublished data of McAlister and a review of Ballard, McCarthy, and Wolfe.

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[1] I. H. Malitson, F. V. Murphy, W. S. Rodney, J. Opt. Soc. Amer. 48, 72 (1958).

[2] I. H. Malitson, J. Opt. Soc. Amer. 52, 1377 (1962).

[3] R. D. Olt, "Synthetic Sapphire and Infrared Optical Material", Linde Bulletin F917-A (1958).

[4] U. P. Oppenheim, U. Even, J. Opt. Soc. Amer. 52, 1078 (1962).

[5] E. Bauer, "Emissivity in the Near Infrared of Particulate Matter in Solid Propellant Rocket Flames", Aeronutronic Report (to be published, 1963).

[6] E. Burstein, J. J. Oberly, E. K. Plyler, Proc. Ind. Acad. Sci. 38, 388 (1948).

TABLE 1

COMPLEX REFRACTIVE INDEX OF ALUMINUM OXIDE AND MAGNESIUM OXIDE

Wavelength	Aluminum Oxide		Magnesium Oxide	
	n_1	n_2	n_1	n_2
0.5μ	1.77	10^{-6}	1.725	$5(10)^{-6}$
1	1.75	10^{-6}	1.720	$7(10)^{-6}$
2	1.74	10^{-6}	1.705	$1.2(10)^{-5}$
3	1.71	10^{-6}	1.690	$1.6(10)^{-5}$
4	1.68	10^{-5}	1.665	$2(10)^{-5}$
5	1.63	10^{-4}	1.64	$5(10)^{-5}$
6	1.54	$2.2(10)^{-4}$	1.60	10^{-4}
8	1.35	$3.3(10)^{-4}$	1.51	$8(10)^{-4}$
10	1.09	$5(10)^{-4}$	1.44	$9(10)^{-4}$

Only a few measurements have been made of the size distribution of alumina particles from solid propellant rocket flames, while none have been reported for magnesium oxide particles. The measurements of Sehgal[7] indicate that the maximum of the curve which gives the number density of alumina particles as a function of size occurs at a radius of about 0.2μ. However, some particles are observed with radii out to 3μ and a few particles with much larger radii. No size distribution is adopted in this report. The reader may average the final results over any desired distribution.

The index of refraction used in this calculation is for sapphire. Actually there is considerable X-ray and electron diffraction evidence to show that the particles are polycrystalline. The characteristic size of the crystalline domain is 0.01μ. Since the domain size is much smaller than the wavelengths of light considered here and since the light beam encounters only a small number of different domains in a particle with a typical radius of 0.2μ, it may be concluded that the effects due to the polycrystalline nature of the particles is probably small. The difference in index of refraction between the different crystalline directions in alumina is small as is the difference in index between the two crystalline forms, α and γ-alumina, which occur under these conditions. Thus the electromagnetic wave does not encounter any regions of greatly changed index of refraction. Both the size distribution and polycrystalline effects are considered in more detail by Bauer.[5]

The scattering and absorption of an electromagnetic wave by a spherical particle can be calculated from the Mie[8] theory when the complex index of refraction is known. Some time ago an efficient program for the calculation of Mie scattering and absorption cross sections was developed by Stull and Plass.[9] The fundamental equations of the Mie theory and the details of the calculation are given in that paper. More recently some improvements in the original program were made by P. J. Wyatt which decreased the running time and increased the allowable range of the parameters.

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[7] R. Sehgal, "An Experimental Investigation of a Gas-Particle System", Jet Prop. Lab. Tech. Rep. 32-238 (March, 1962).

[8] G. Mie, Ann. Physik 25, 377 (1908).

[9] V. R. Stull, G. N. Plass, J. Opt. Soc. Amer. 50, 121 (1960).

The cross sections obtained in this manner from the Mie Theory are given in Tables 2 and 3 for aluminum oxide and magnesium oxide respectively. The first two columns give real (n_1) and imaginary (n_2) parts of the index of refraction. The wavelength is given in the third column. The radius of the particle is given in the fourth column. The efficiency factors, Q, for absorption, scattering, and extinction are given in the last columns. The efficiency factor is defined as the cross section divided by the area of the particle.

It appears from these results that the emissivity of aluminum and magnesium oxide is relatively small for the number and size of particles reported in the literature as occurring in rocket exhausts. Only the presence of a fair number of relatively large particles could appreciably increase the emissivity to the blackbody level. Thus, the most important effect of these particles appears to be in their ability to scatter radiation. The application of the Mie theory results to actual rocket motors has been considered in more detail by Bauer.[5] He also obtains approximate solutions for the radiative transfer equations which describe the scattering of radiation in rocket exhausts by these particles.

ACKNOWLEDGMENT

TABLE 2

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY ALUMINUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.77	10^{-6}	0.5μ	0.1μ	$4.74 \ (10)^{-6}$	1.074	1.074
			0.2	$1.59 \ (10)^{-5}$	4.68	4.68
			0.4	$6.08 \ (10)^{-5}$	2.21	2.21
			0.6	$4.26 \ (10)^{-5}$	2.78	2.78
			0.8	$5.01 \ (10)^{-5}$	2.33	2.33
			1.1	$8.85 \ (10)^{-5}$	2.09	2.09
			1.6	$9.94 \ (10)^{-5}$	2.38	2.38
			2.1	$1.183(10)^{-4}$	2.22	2.22
			2.6	$1.292(10)^{-4}$	2.12	2.12
			3.1	$2.14 \ (10)^{-4}$	2.22	2.22
			5.1	$2.95 \ (10)^{-4}$	2.14	2.14
1.75	10^{-6}	1μ	0.1μ	$1.32 \ (10)^{-6}$	$7.44 \ (10)^{-2}$	$7.44 \ (10)^{-2}$
			0.2	$4.63 \ (10)^{-6}$	1.018	1.018
			0.4	$1.603(10)^{-5}$	4.68	4.68
			0.6	$3.26 \ (10)^{-5}$	3.90	3.90
			0.8	$4.66 \ (10)^{-5}$	1.813	1.813
			1.1	$4.30 \ (10)^{-5}$	2.97	2.97
			1.6	$7.20 \ (10)^{-5}$	2.25	2.25
			2.1	$7.84 \ (10)^{-5}$	1.952	1.952
			2.6	$8.50 \ (10)^{-5}$	2.48	2.48
			3.1	$1.198(10)^{-4}$	2.49	2.49
			5.1	$1.533(10)^{-4}$	2.36	2.36

TABLE 2 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY ALUMINUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.74	10^{-6}	2μ	0.1μ	$5.09\ (10)^{-7}$	$4.32\ (10)^{-3}$	$4.32\ (10)^{-3}$
			0.2	$1.327(10)^{-6}$	$7.27\ (10)^{-2}$	$7.27\ (10)^{-2}$
			0.4	$4.59\ (10)^{-6}$	$9.90\ (10)^{-1}$	$9.90\ (10)^{-1}$
			0.6	$9.21\ (10)^{-6}$	3.12	3.12
			0.8	$1.627(10)^{-5}$	4.68	4.68
			1.1	$2.01\ (10)^{-5}$	3.69	3.69
			1.6	$4.03\ (10)^{-5}$	1.677	1.677
			2.1	$3.65\ (10)^{-5}$	2.62	2.62
			2.6	$1.046(10)^{-4}$	3.19	3.19
			3.1	$6.00\ (10)^{-5}$	1.868	1.868
			5.1	$9.92\ (10)^{-5}$	2.49	2.49
1.71	10^{-6}	3μ	0.1μ	$2.82\ (10)^{-7}$	$7.91\ (10)^{-4}$	$7.91\ (10)^{-4}$
			0.2	$7.53\ (10)^{-7}$	$1.299(10)^{-2}$	$1.299(10)^{-2}$
			0.4	$2.12\ (10)^{-6}$	$2.16\ (10)^{-1}$	$2.16\ (10)^{-1}$
			0.6	$4.59\ (10)^{-6}$	$9.10\ (10)^{-1}$	$9.10\ (10)^{-1}$
			0.8	$9.80\ (10)^{-6}$	2.55	2.55
			1.1	$1.496(10)^{-5}$	3.92	3.92
			1.6	$1.991(10)^{-5}$	4.33	4.33
			2.1	$3.29\ (10)^{-5}$	2.51	2.51
			2.6	$3.39\ (10)^{-5}$	1.919	1.919
			3.1	$5.66\ (10)^{-5}$	2.40	2.40
			5.1	$5.48\ (10)^{-5}$	2.08	2.08

TABLE 2 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY ALUMINUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.68	10^{-5}	4μ	0.1μ	$1.658(10)^{-6}$	$2.33\ (10)^{-4}$	$2.35\ (10)^{-4}$
			0.2	$5.60\ (10)^{-6}$	$3.78\ (10)^{-3}$	$3.78\ (10)^{-3}$
			0.4	$1.404(10)^{-5}$	$6.29\ (10)^{-2}$	$6.29\ (10)^{-2}$
			0.6	$2.64\ (10)^{-5}$	$3.13\ (10)^{-1}$	$3.13\ (10)^{-1}$
			0.8	$4.52\ (10)^{-5}$	$8.35\ (10)^{-1}$	$8.35\ (10)^{-1}$
			1.1	$9.93\ (10)^{-5}$	2.50	2.50
			1.6	$1.651(10)^{-4}$	4.42	4.42
			2.1	$2.14\ (10)^{-4}$	4.71	4.71
			2.6	$2.44\ (10)^{-4}$	3.60	3.60
			3.1	$2.79\ (10)^{-4}$	2.36	2.36
			5.1	$1.300(10)^{-3}$	3.46	3.46
1.63	10^{-4}	5μ	0.1μ	$2.17\ (10)^{-5}$	$8.44\ (10)^{-5}$	$1.061(10)^{-4}$
			0.2	$4.72\ (10)^{-5}$	$1.361(10)^{-3}$	$1.408(10)^{-3}$
			0.4	$1.063(10)^{-4}$	$2.23\ (10)^{-2}$	$2.24\ (10)^{-2}$
			0.6	$1.875(10)^{-4}$	$1.144(10)^{-1}$	$1.145(10)^{-1}$
			0.8	$2.95\ (10)^{-4}$	$3.43\ (10)^{-1}$	$3.44\ (10)^{-1}$
			1.1	$5.40\ (10)^{-4}$	$9.58\ (10)^{-1}$	$9.59\ (10)^{-1}$
			1.6	$9.52\ (10)^{-4}$	2.66	2.66
			2.1	$1.558(10)^{-3}$	4.16	4.16
			2.6	$2.18\ (10)^{-3}$	4.70	4.70
			3.1	$2.68\ (10)^{-3}$	4.11	4.11
			5.1	$3.85\ (10)^{-3}$	1.960	1.963

TABLE 2 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY ALUMINUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.54	$2.2(10)^{-4}$	6μ	0.1μ	$4.42\ (10)^{-5}$	$3.16\ (10)^{-5}$	$7.58\ (10)^{-5}$
			0.2	$9.08\ (10)^{-5}$	$5.07\ (10)^{-4}$	$5.98\ (10)^{-4}$
			0.4	$1.965(10)^{-4}$	$8.20\ (10)^{-3}$	$8.39\ (10)^{-3}$
			0.6	$3.28\ (10)^{-4}$	$4.17\ (10)^{-2}$	$4.21\ (10)^{-2}$
			0.8	$4.91\ (10)^{-4}$	$1.295(10)^{-1}$	$1.300(10)^{-1}$
			1.1	$7.94\ (10)^{-4}$	$4.04\ (10)^{-1}$	$4.05\ (10)^{-1}$
			1.6	$1.667(10)^{-3}$	1.275	1.277
			2.1	$2.14\ (10)^{-3}$	2.33	2.33
			2.6	$3.23\ (10)^{-3}$	3.52	3.52
			3.1	$3.82\ (10)^{-3}$	3.90	3.90
			5.1	$5.88\ (10)^{-3}$	2.95	2.95
1.35	$3.3(10)^{-4}$	8μ	0.1μ	$4.97\ (10)^{-5}$	$4.70\ (10)^{-6}$	$5.44\ (10)^{-5}$
			0.2	$1.140(10)^{-4}$	$7.51\ (10)^{-5}$	$1.891(10)^{-4}$
			0.4	$2.39\ (10)^{-4}$	$1.195(10)^{-3}$	$1.434(10)^{-3}$
			0.6	$3.74\ (10)^{-4}$	$5.99\ (10)^{-3}$	$6.36\ (10)^{-3}$
			0.8	$5.25\ (10)^{-4}$	$1.855(10)^{-2}$	$1.907(10)^{-2}$
			1.1	$7.84\ (10)^{-4}$	$6.24\ (10)^{-2}$	$6.32\ (10)^{-2}$
			1.6	$1.274(10)^{-3}$	$2.22\ (10)^{-1}$	$2.23\ (10)^{-1}$
			2.1	$1.868(10)^{-3}$	$4.65\ (10)^{-1}$	$4.67\ (10)^{-1}$
			2.6	$2.62\ (10)^{-3}$	$8.64\ (10)^{-1}$	$8.67\ (10)^{-1}$
			3.1	$3.11\ (10)^{-3}$	1.292	1.295
			5.1	$5.69\ (10)^{-3}$	3.06	3.07

TABLE 2 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY ALUMINUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.09	$5 \ (10)^{-4}$	10μ	0.1μ	$5.69 \ (10)^{-5}$	$1.449(10)^{-7}$	$5.71 \ (10)^{-5}$
			0.2	$1.612(10)^{-4}$	$2.30 \ (10)^{-6}$	$1.636(10)^{-4}$
			0.4	$3.24 \ (10)^{-4}$	$3.63 \ (10)^{-5}$	$3.60 \ (10)^{-4}$
			0.6	$4.91 \ (10)^{-4}$	$1.795(10)^{-4}$	$6.70 \ (10)^{-4}$
			0.8	$6.62 \ (10)^{-4}$	$5.48 \ (10)^{-4}$	$1.21 \ (10)^{-3}$
			1.1	$9.25 \ (10)^{-4}$	$1.823(10)^{-3}$	$2.75 \ (10)^{-3}$
			1.6	$1.382(10)^{-3}$	$6.86 \ (10)^{-3}$	$8.24 \ (10)^{-3}$
			2.1	$1.846(10)^{-3}$	$1.602(10)^{-2}$	$1.786(10)^{-2}$
			2.6	$2.31 \ (10)^{-3}$	$2.84 \ (10)^{-2}$	$3.07 \ (10)^{-2}$
			3.1	$2.80 \ (10)^{-3}$	$4.35 \ (10)^{-2}$	$4.63 \ (10)^{-2}$
			5.1	$4.78 \ (10)^{-3}$	$1.47 \ (10)^{-1}$	$1.52 \ (10)^{-1}$

TABLE 3

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY MAGNESIUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.725	$5(10)^{-6}$	0.5μ	0.1μ	$2.34 (10)^{-5}$	0.950	0.950
			0.2	$8.24 (10)^{-5}$	4.64	4.64
			0.4	$1.723(10)^{-4}$	1.620	1.620
			0.6	$3.49 (10)^{-4}$	3.55	3.55
			0.8	$2.88 (10)^{-4}$	2.13	2.13
			1.1	$3.36 (10)^{-4}$	2.10	2.10
			1.6	$4.38 (10)^{-4}$	2.42	2.42
			2.1	$5.89 (10)^{-4}$	2.11	2.11
			2.6	$6.56 (10)^{-4}$	2.20	2.20
			3.1	$7.59 (10)^{-4}$	2.14	2.14
			5.1	$1.226(10)^{-3}$	2.17	2.17
1.72	$7(10)^{-6}$	1μ	0.1μ	$9.65 (10)^{-6}$	$6.94 (10)^{-2}$	$6.94 (10)^{-2}$
			0.2	$3.27 (10)^{-5}$	0.936	0.936
			0.4	$1.157(10)^{-4}$	4.63	4.63
			0.6	$2.23 (10)^{-4}$	3.99	3.99
			0.8	$2.32 (10)^{-4}$	1.629	1.629
			1.1	$3.66 (10)^{-4}$	3.23	3.23
			1.6	$4.05 (10)^{-4}$	2.08	2.08
			2.1	$4.27 (10)^{-4}$	2.29	2.29
			2.6	$5.88 (10)^{-4}$	2.54	2.54
			3.1	$9.53 (10)^{-4}$	2.21	2.21
			5.1	$8.85 (10)^{-4}$	2.06	2.06

TABLE 3 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY MAGNESIUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.705	$1.2(10)^{-5}$	2μ	0.1μ	$6.54\ (10)^{-6}$	$4.01\ (10)^{-3}$	$4.01\ (10)^{-3}$
			0.2	$1.660(10)^{-5}$	$6.70\ (10)^{-2}$	$6.70\ (10)^{-2}$
			0.4	$5.54\ (10)^{-5}$	$8.98\ (10)^{-1}$	$8.98\ (10)^{-1}$
			0.6	$1.153(10)^{-4}$	2.96	2.96
			0.8	$1.992(10)^{-4}$	4.57	4.57
			1.1	$2.35\ (10)^{-4}$	4.00	4.00
			1.6	$3.66\ (10)^{-4}$	1.714	1.714
			2.1	$8.07\ (10)^{-4}$	2.67	2.67
			2.6	$5.20\ (10)^{-4}$	2.89	2.89
			3.1	$5.95\ (10)^{-4}$	1.929	1.929
			5.1	$1.021(10)^{-3}$	2.55	2.55
1.69	$1.6(10)^{-5}$	3μ	0.1μ	$5.33\ (10)^{-6}$	$7.56\ (10)^{-4}$	$7.62\ (10)^{-4}$
			0.2	$1.293(10)^{-5}$	$1.240(10)^{-2}$	$1.241(10)^{-2}$
			0.4	$3.49\ (10)^{-5}$	$2.05\ (10)^{-1}$	$2.05\ (10)^{-1}$
			0.6	$7.32\ (10)^{-5}$	$8.60\ (10)^{-1}$	$8.60\ (10)^{-1}$
			0.8	$1.567(10)^{-4}$	2.38	2.38
			1.1	$2.29\ (10)^{-4}$	3.70	3.70
			1.6	$3.24\ (10)^{-4}$	4.48	4.48
			2.1	$4.63\ (10)^{-4}$	2.59	2.59
			2.6	$5.43\ (10)^{-4}$	1.835	1.835
			3.1	$6.36\ (10)^{-4}$	2.10	2.10
			5.1	$8.96\ (10)^{-4}$	1.923	1.924

TABLE 3 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY MAGNESIUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.665	$2(10)^{-5}$	4μ	0.1μ	$4.69\ (10)^{-6}$	$2.25\ (10)^{-4}$	$2.30\ (10)^{-4}$
			0.2	$1.170(10)^{-5}$	$3.65\ (10)^{-3}$	$3.66\ (10)^{-3}$
			0.4	$2.83\ (10)^{-5}$	$6.05\ (10)^{-2}$	$6.05\ (10)^{-2}$
			0.6	$5.30\ (10)^{-5}$	$3.00\ (10)^{-1}$	$3.00\ (10)^{-1}$
			0.8	$8.96\ (10)^{-5}$	$7.99\ (10)^{-1}$	$7.99\ (10)^{-1}$
			1.1	$1.956(10)^{-4}$	2.38	2.38
			1.6	$3.27\ (10)^{-4}$	4.30	4.30
			2.1	$4.32\ (10)^{-4}$	4.76	4.76
			2.6	$5.00\ (10)^{-4}$	3.78	3.78
			3.1	$5.64\ (10)^{-4}$	2.50	2.50
			5.1	$1.082(10)^{-3}$	2.94	2.94
1.64	$5(10)^{-5}$	5μ	0.1μ	$1.080(10)^{-5}$	$8.66\ (10)^{-5}$	$9.74\ (10)^{-5}$
			0.2	$2.31\ (10)^{-5}$	$1.396(10)^{-3}$	$1.419(10)^{-3}$
			0.4	$5.29\ (10)^{-5}$	$2.29\ (10)^{-2}$	$2.30\ (10)^{-2}$
			0.6	$9.35\ (10)^{-5}$	$1.177(10)^{-1}$	$1.178(10)^{-1}$
			0.8	$1.475(10)^{-4}$	$3.54\ (10)^{-1}$	$3.54\ (10)^{-1}$
			1.1	$2.73\ (10)^{-4}$	$9.91\ (10)^{-1}$	$9.91\ (10)^{-1}$
			1.6	$4.76\ (10)^{-4}$	2.72	2.72
			2.1	$7.79\ (10)^{-4}$	4.22	4.22
			2.6	$1.099(10)^{-3}$	4.75	4.75
			3.1	$1.393(10)^{-3}$	4.14	4.14
			5.1	$1.946(10)^{-3}$	2.05	2.05

TABLE 3 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY MAGNESIUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.60	10^{-4}	6μ	0.1μ	$1.764(10)^{-5}$	$3.76 (10)^{-5}$	$5.52 (10)^{-5}$
			0.2	$3.98 (10)^{-5}$	$6.04 (10)^{-4}$	$6.44 (10)^{-4}$
			0.4	$8.63 (10)^{-5}$	$9.82 (10)^{-3}$	$9.91 (10)^{-3}$
			0.6	$1.455(10)^{-4}$	$5.05 (10)^{-2}$	$5.06 (10)^{-2}$
			0.8	$2.21 (10)^{-4}$	$1.580(10)^{-1}$	$1.582(10)^{-1}$
			1.1	$3.67 (10)^{-4}$	$4.97 (10)^{-1}$	$4.97 (10)^{-1}$
			1.6	$8.43 (10)^{-4}$	1.661	1.662
			2.1	$1.020(10)^{-3}$	2.69	2.69
			2.6	$1.511(10)^{-3}$	3.99	3.99
			3.1	$2.03 (10)^{-3}$	4.42	4.42
			5.1	$3.16 (10)^{-3}$	2.27	2.27
1.51	8×10^{-4}	8μ	0.1μ	$1.198(10)^{-4}$	$9.08 (10)^{-6}$	$1.289(10)^{-4}$
			0.2	$2.51 (10)^{-4}$	$1.455(10)^{-4}$	$3.97 (10)^{-4}$
			0.4	$5.25 (10)^{-4}$	$2.34 (10)^{-3}$	$2.86 (10)^{-3}$
			0.6	$8.37 (10)^{-4}$	$1.190(10)^{-2}$	$1.274(10)^{-2}$
			0.8	$1.206(10)^{-3}$	$3.76 (10)^{-2}$	$3.88 (10)^{-2}$
			1.1	$1.876(10)^{-3}$	$1.305(10)^{-1}$	$1.323(10)^{-1}$
			1.6	$3.28 (10)^{-3}$	$4.72 (10)^{-1}$	$4.75 (10)^{-1}$
			2.1	$5.56 (10)^{-3}$	1.053	1.059
			2.6	$7.42 (10)^{-3}$	1.935	1.942
			3.1	$9.02 (10)^{-3}$	2.47	2.48
			5.1	$1.655(10)^{-2}$	4.05	4.06

TABLE 3 (Continued)

EFFICIENCY FACTORS FOR ABSORPTION AND SCATTERING BY MAGNESIUM OXIDE

n_1	n_2	Wavelength	Radius	Q_{abs}	Q_{sca}	Q_{ext}
1.44	9×10^{-4}	10μ	0.1μ	$1.168(10)^{-4}$	$2.89\ (10)^{-6}$	$1.197(10)^{-4}$
			0.2	$2.40\ (10)^{-4}$	$4.62\ (10)^{-5}$	$2.86\ (10)^{-4}$
			0.4	$4.86\ (10)^{-4}$	$7.40\ (10)^{-4}$	$1.225(10)^{-3}$
			0.6	$7.55\ (10)^{-4}$	$3.74\ (10)^{-3}$	$4.50\ (10)^{-3}$
			0.8	$1.055(10)^{-3}$	$1.181(10)^{-2}$	$1.286(10)^{-2}$
			1.1	$1.574(10)^{-3}$	$4.16\ (10)^{-2}$	$4.32\ (10)^{-2}$
			1.6	$2.62\ (10)^{-3}$	$1.701(10)^{-1}$	$1.727(10)^{-1}$
			2.1	$3.85\ (10)^{-3}$	$4.05\ (10)^{-1}$	$4.09\ (10)^{-1}$
			2.6	$5.54\ (10)^{-3}$	$7.34\ (10)^{-1}$	$7.40\ (10)^{-1}$
			3.1	$7.55\ (10)^{-3}$	1.267	1.274
			5.1	$8.32\ (10)^{-3}$	1.660	1.669

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AND MAGNESIUM OXIDE. Final Report, 27 May 1963,
15p. incl tables.   Unclassified Report

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radiation by spherical particles of aluminum
oxide and magnesium oxide is calculated from the
Mie theory. The complex index of refraction was
taken from the best available experimental data.
Tables of the efficiency factors for scattering,
absorption, and extinction are given for particle
radii from 0.1 to 5.1μ and a range of wave-
lengths from 0.5 to 10μ.

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2. Electromagnetic
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